THE EFFECTS OF CONDUCTIVITY OF THE MATERIALS ASSOCIATED WITH THE WEDGES ON THE LOSS BY DIFFRACTION

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ABSTRACT

Radio wave signals do not travel in a straight line path. There may be some obstacles between the source and the destination which cause diffraction, reflection, scattering and attenuation. There are some types of obstacles such as knife edge, wedges and round edges. This paper shows the diffraction loss caused by wedges based on Uniformal Theory of Diffraction (UTD) given in (ITU-R Recommendation P.526-12) using Matlab software. It could be said that this is an important method because radio waves travel over wedge shaped roofs of buildings and corners of the buildings. In addition this diffraction loss changes for both roofs and corners for a particular obstruction material. Furthermore, the electrical properties of the wedge shaped obstacles are affecting the diffraction loss such as conductivity and dielectric constant. The result shows that higher conductivity leads to have a higher amplitude oscillation at the receiver.

KEYWORDS

Radio wave propagation, diffraction, wedge diffraction

1. INTRODUCTION

1.1 BACKGROUND

Nowadays, communication technology has developed rapidly as compared to the past. Radio waves are electromagnetic waves which travel from a transmitting point to a receiving point. The length of the path between the transmitter and the receiver is different for each type of propagation, such as mobile or satellite communication. In mobile communication, when the signal travels from the transmitter to the receiver, 'it does not simply travel in a straight line' (Barclay, 2003 p.129). There may be some obstacles and physical terrain that can cause reflection, scattering and diffraction of the signal, with the addition of a direct signal which may cause multipath signals at the receiving point. In addition, these different signals may cause interference when they are out of phase which can decrease the strength of the signal at the receiver [1].

Basically, Diffraction is based on Huygens' Principle which says in radio wave propagation every point of the wave acts a source for the next point [2]. For example, when signals are obstructed by an edge they act as a new source to the receiver from the edge as shown in Figure (1). Diffraction occurs when the radio waves strike the edge of an obstacle which is situated between the transmitter and the receiver. 'The apparent bending of radio waves around the edge of an obstruction is known as diffraction' (Parsons, 2000 p.34). However, the received signal does not decrease to the lowest strength directly after the obstacle. It can be said that this is one of the most important phenomena in terms of propagation, because there are a range of types of obstacles such as knife-edge, round, random and wedges. However, the rate of loss due to diffraction varies for each type of obstacle.
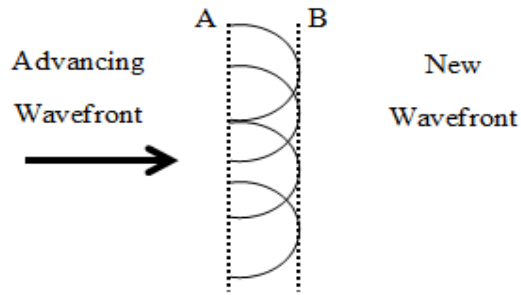
Figure 1. Huygens' construction [1]

As can be seen from Figure (1) the Advancing Wavefront comes from the original source and at each point of line A produces a new source to line B in the direction of propagation.

1.2 KNIFE-EDGE DIFFRACTION:

This type of diffraction is the result of radio waves striking an obstacle with a thin or sharp edge [1]. The geometry of knife edge diffraction is shown in Figure (2) and Figure (3)
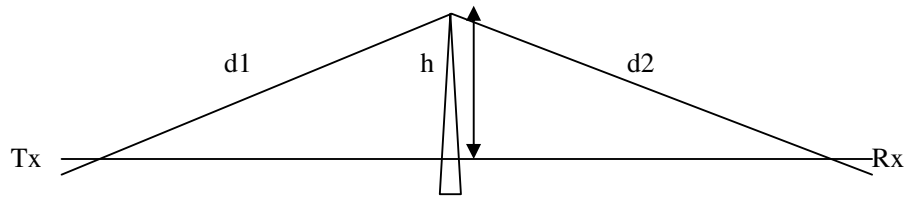

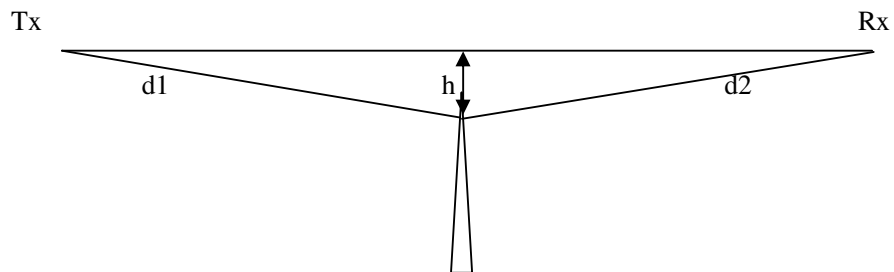Figure 2. Geometry of knife edge diffraction height > 0 [1]

Figure 3. Geometry of knife edge diffraction height < 0 [1]

d1: distance from transmitter to the edge.
d2: distance from the edge to the receiver.
h: height of the obstacle

As can be seen from Figures (2) and (3), the signal travels from the transmitter and is diffracted by the edge of the obstacle. In Figure (2), the height of the obstacle is positive because it is above the line of sight. On the other hand, in Figure (3), the height is negative because the edge is below the line of sight. To calculate the loss associated with this type of diffraction, a single

dimensionless parameter - ν - can be used because the other parameters can be combined with it as in [3]. Moreover, the formula for calculating the ν parameter in this case is:

$$v = h\sqrt{\frac{2(d1+d2)}{\lambda\, d1\, d2}} \qquad [3] \qquad (1)$$

Furthermore, the diffraction loss J (ν) can be calculated as follows:

$$J(v) = 6.9 + 20 \log\left[\sqrt{(v-0.1)^2 + 1} + v - 0.1\right] \quad (dB) \quad [3] \qquad (2)$$

Moreover, (ITU-R Recommendation) has provided a Matlab function to calculate this loss in (ITU-R Recommendation p.525-12). Figure (4) shows the diffraction loss versus the ν parameter.
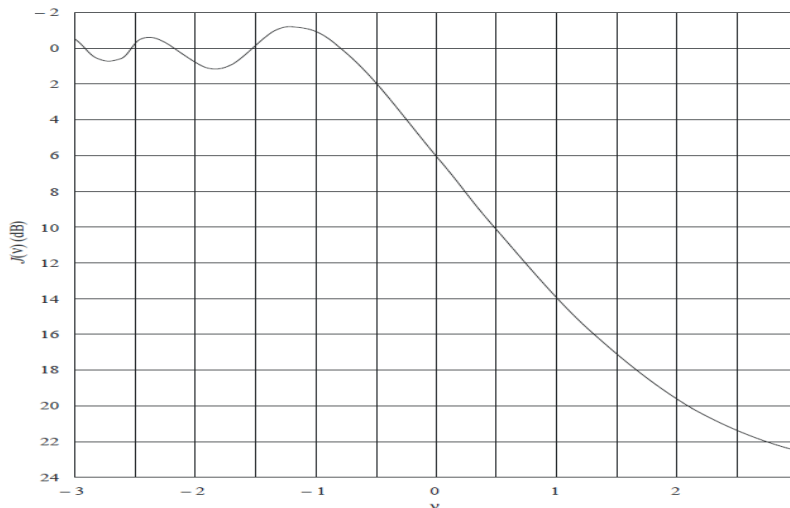

Figure 4. Knife edge diffraction loss [3]

Figure (4) shows how the loss varies according to the ν parameter in knife edge diffraction. However, it can be assumed that for a value of ν below -0.7, the loss is zero dB [3]. For values of ν greater than -0.7 the received signal strength decrease gradually such as at ν is equal to 3 the loss is nearly 22 dB. This means, the received amplitude of the signal has decreased.

1.3 DIFFRACTION OVER WEDGES:

Furthermore, it is more interesting to investigate the effects on diffraction loss of the other types of edge associated with obstacles such as curved edges or wedges since these are more complex to deal with. Wedge diffraction was based on the Geometrical Theory of Diffraction (GTD) which was published by Keller in 1962 [5]. After that Kouyoumjian Pathak extended this GTD to UTD [6]. Moreover, for a giving incident angle, the receiving point may receive more than the diffracted signal, depending on its position. For example it may receive a signal reflected by the wedge and the direct signal (Line of Sight). To investigate how many signals the receiver receives, two boundaries can be defined. One of them is the shadow boundary which below this the direct signal and the reflected signal are not available. The other boundary is the reflection boundary which below this the reflected signal is not available [1]. These boundaries are illustrated in Figures (5, 6, and 7)
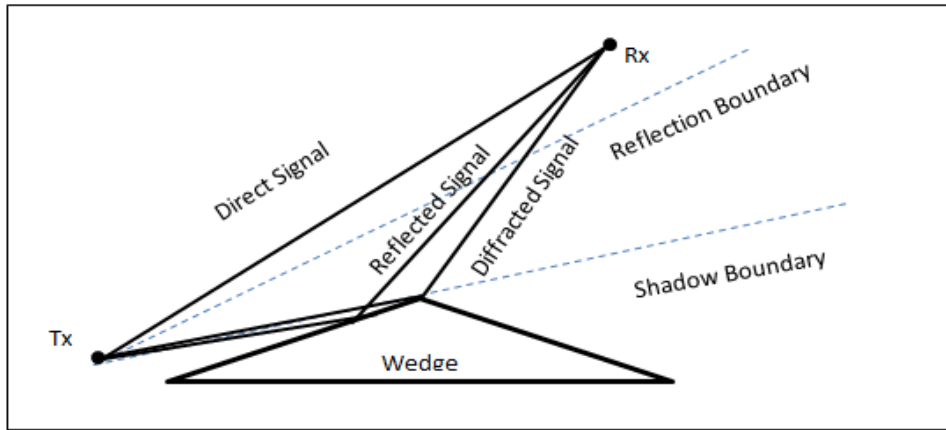
Figure 5. When the receiving point is above the boundaries. [1]

As can be seen from the above figure, the receiver locates above both boundaries. In this case the receiver receives the direct signal, a reflected signal and a diffracted signal due to the edge of the wedge.
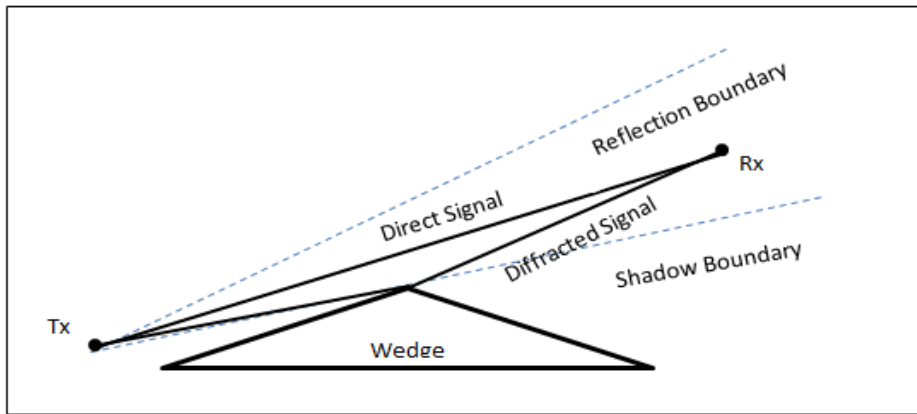

Figure 6. When the receiving point is between the two boundaries [1]

As can be seen from the above figure, the receiver is located above the shadow and below the reflection boundary. This leads to the absence of a reflected signal, and the receiver receives only the direct and the diffracted signal.

The last case is when the receiver's position is below the shadow boundary. In this case, both the reflected and the direct signal will be absent, and the receiver receives only the diffracted signal as shown in Figure (7).
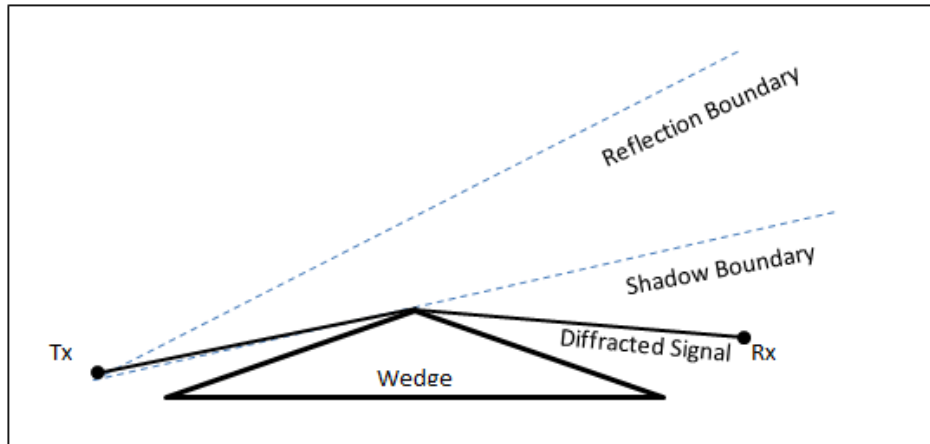
Figure 7. When the receiving point is below two boundaries [1]

Measuring diffraction loss due to wedges is important because in western or rainy countries such as the UK, most of the roofs of the buildings are wedge shaped. In addition, signals travel around the corners of the buildings and these corners are considered as a wedge in terms of parallel polarization unlike roofs which are considered in terms of perpendicular polarization and these corners are causing diffraction. In addition, the material which makes up the wedge or the corner affects the rate of the diffraction loss. For this reason the dielectric constant and conductivity of the wedge material are taken into account [3]. The aim of this paper is to implement a Matlab code to investigate and validate diffraction loss caused by a finitely conducting wedge for both perpendicular and parallel polarization based on (ITU-R Recommendation p.526-12) as well as to show how this loss varies according to the material used to make the wedge. Finally, it compares the relationship between knife edge diffraction and UTD by showing how UTD can be used to obtain a knife edge diffraction result as well as it investigates and compares the rate of varying diffraction loss for both knife edge and wedge versus v parameter.

2. METHODOLOGY

In this case of study, Diffraction by a single rectangular aperture (wedge) has been implemented by using Matlab software based on ITU document (ITU-R P.526 - 12).This method is originally based on Uniformal Theory of Diffraction (UTD) which made of some mathematical formulas and calculations. Additionally, the reflection from the wedge and the Line of Sight signals are considered. The geometry of wedge diffraction can be seen in the Figure (8).
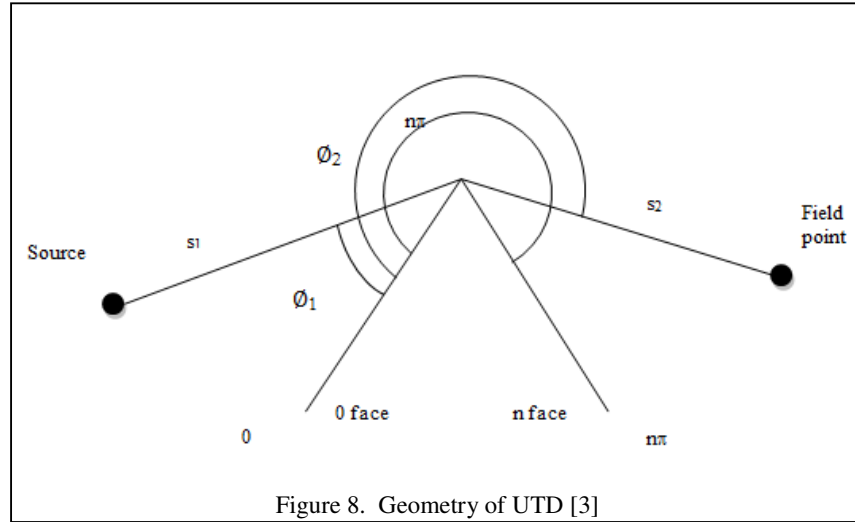
Figure 8. Geometry of UTD [3]

As can be seen from the above figure, there are some parameters and they have effects on the electric field at the Receiver. The wedge has two faces, 0 face and n face. The angles are measured from the 0 face.

The received field by the diffraction can be calculated by using the below equation.

$$e_{UTD} = e_0 \frac{exp(-jks_2)}{s_2} D_{||}^{\perp} \sqrt{\frac{S_1}{S_2(S_1+S_2)}} \cdot exp(-jks_1) \qquad [3] \qquad (3)$$

Where:

e_{UTD}: electric field at the receiver.
e_0: source amplitude
s_1: distance from the transmitter to the edge of the wedge.
s_2: distance from the edge of the wedge to the receiver.
k: wave number which equals to $2\pi/\lambda$.

The external angle of the wedge is $n\pi$. However the internal angle of the wedge is $2\pi-n\pi$.

$D_{||}^{\perp}$ is Diffraction coefficient for both parallel incident on the edge of the wedge or perpendicular. This coefficient can be calculated using the following formula.

$$D_{||}^{\perp} = \frac{-exp(-j\pi/4)}{2n\sqrt{2\pi k}} \left\{ \begin{array}{l} cot\left(\frac{\pi+(\varnothing 2 - \varnothing 1)}{2n}\right) . F(kLa^+ (\varnothing 2 - \varnothing 1)) \\ cot\left(\frac{\pi-(\varnothing 2 - \varnothing 1)}{2n}\right) . F(kLa^- (\varnothing 2 - \varnothing 1)) \\ R_{0||}^{\perp} . cot\left(\frac{\pi-(\varnothing 2 + \varnothing 1)}{2n}\right) . F(kLa^- (\varnothing 2 + \varnothing 1)) \\ R_{n||}^{\perp} . cot\left(\frac{\pi+(\varnothing 2 + \varnothing 1)}{2n}\right) . F(kLa^+ (\varnothing 2 \mid \varnothing 1)) \end{array} \right\} \qquad [3] \qquad (4)$$

$\varnothing 1$: incident angle.

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$\emptyset 2$: angle of diffraction.

n: external wedge angle as a multiple of π radian

The formula of the diffraction parameter includes Fresnel integral which is:

$$F(x) = 2j\sqrt{x} \cdot \exp(jx) \cdot \int_{\sqrt{x}}^{\infty} \exp(-jt^2)dt \qquad [3] \qquad (5)$$

Where $x = kLa^{\pm}(\emptyset 2 \pm \emptyset 1)$.

$$L = \frac{s_2 \cdot s_1}{s_2 + s_1} \qquad [3] \qquad (6)$$

$$a^{\pm}(\beta) = 2 \cos^2\left(\frac{2n\pi N^{\pm} - \beta}{2}\right) \qquad [3] \qquad (7)$$

$$N^{\pm} = \frac{\beta \pm \pi}{2n\pi} \qquad [3] \qquad (8)$$

$N^{\pm}$: are Integers which nearly satisfy the equation.

There are two different ways to calculate this integral. One of them is using normal calculation. Another one is using an alternative way which is based on Boersma's approximation [4]. Both of them lead to the same result. However, for this case of study the Boersma's approximation has been used.

Furthermore, it includes reflection coefficient (R) from the wedge for parallel or perpendicular incident which depends on the conductivity and dielectric constant of the wedge material. It can be said that this coefficient is two parts for each case of polarization which are R0 and Rn for 0 and n faces [3].

Reflection Coefficient for parallel incident is:

$$R_{||} = \frac{\eta \cdot \sin(\emptyset) - \sqrt{\eta - \cos(\emptyset)^2}}{\eta \cdot \sin(\emptyset) + \sqrt{\eta - \cos(\emptyset)^2}} \qquad [3] \qquad (9)$$

Reflection Coefficient for perpendicular incident is:

$$R_{\perp} = \frac{\sin(\emptyset) - \sqrt{\eta - \cos(\emptyset)^2}}{\sin(\emptyset) + \sqrt{\eta - \cos(\emptyset)^2}} \qquad [3] \qquad (10)$$

Where,

$\emptyset = \emptyset 1$ for R_0

$\emptyset = (n\pi - \emptyset 1)$ for R_n

$$\eta = \varepsilon_r - j * 18 * 10^9 * \frac{\sigma}{f} \qquad [3] \qquad (11)$$

ε_r : Relative dielectric constant of the material of the wedge.

σ : Material conductivity.

f : Frequency of the radio wave

In addition, the reflection angle should be found. This can be done using Cartesian axes. First of all, we found the position of the transmitter and the receiver at the coordinate then the reflection angle can be found. However, the both distances by the reflected and line of sight rays should be found in order to calculate the loss happened due to them using the following equation.

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$$eLD = \frac{\exp(-jks)}{s} \qquad [3] \qquad (12)$$

Where s is the distance by the reflected ray or the Line Of Sight. However, for calculating loss caused by reflection, the nominator should be multiplied by the reflection angle.

Then, the boundaries should be defined. To do this, we need to divide the area into three separate parts. One of them is the above reflection boundary area where the receiver receives the whole three rays. Another boundary is between shadow boundary and the reflection boundary where the receiver receives only direct and diffracted signal. The last one is the below shadow boundary where only the diffracted signal is being receiving.

To find the reflection boundary this equation should be used.

$$\text{Reflection boundary (Degree)} = 180 - \emptyset 1 \qquad (13)$$

So for $\emptyset 2$ smaller than reflection boundary means the receiver locates above the reflection boundary so it receives a combination of the three rays.

To find the shadow boundary this equation should be used.

$$\text{Shadow boundary (Degree)} = 180 + \emptyset 1 \qquad (14)$$

So for $\emptyset 2$ greater or equal than the reflection boundary and smaller than the shadow boundary means the receiver locates between the boundaries so it receives a combination of diffracted and direct rays.

Finally, for $\emptyset 2$ greater than shadow boundary means the receiver locates below the shadow boundary so it receives only the diffracted ray.

For this case of study, the transmitter is located in a place with incident angle of 45° and the receiving point is moving from the transmitter to behind the wedge from angle of diffraction of 90° to 240° in order to investigate the effects of all positions (above, between and below the boundaries) on the diffraction. In addition, the frequency of 1800 MHz has been used to investigate the GSM propagation. Also the distances from the transmitter to the wedge and from the wedge to the receiver is assigned to 15 meter for a perfectly conducting wedge which means the conductivity is the highest. Thus the R parameters in equations (9) and (10) will be -1. Moreover, different types of materials are investigated in order to observe how loss changes according to the type of the material of the wedge such as wood, brick.

3. Results and Discussion:

In this part of the Work several outputs have been observed to predict different effects of individual material and parameters on the diffraction loss.

Firstly, we observed a perpendicular polarization which means diffraction by the ridge of a wedge shaped roof as shown in figure (9). The wedge is considered as a finitely conducting wedge. This means, the conductivity of the wedge material is highest and this makes both R0 and Rn in equation (10) equal to -1. In addition the frequency of GSM has been used which is 1800 MHz. Also, the other parameters are:

The internal angle of the wedge = 90 degree.
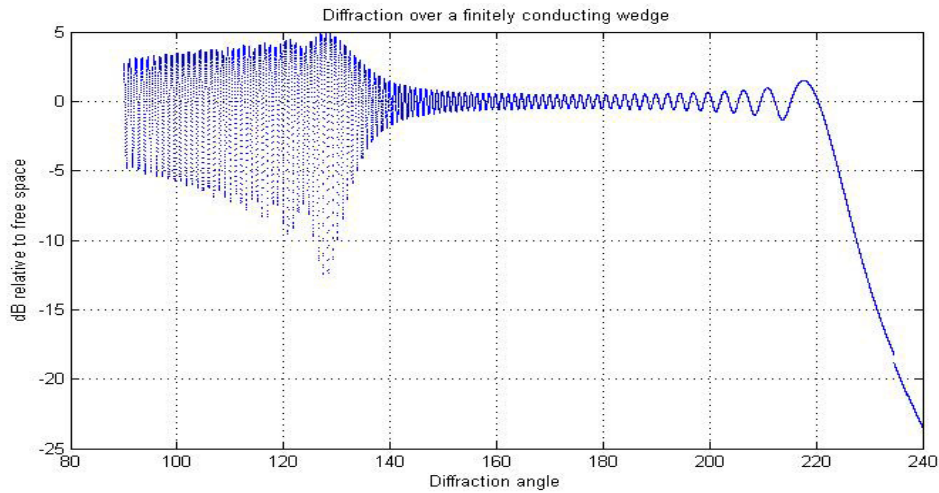s1 = 15 meter.
s2 = 15 meter.

Figure 9. Diffraction over a finitely conducting wedge

As can be seen from the above figure, when the receiver locates in an angle lower than the reflection boundary the rate of changing amplitude of the received signal is very fast. This is also called fast fading or complicated lobing because at these areas the receiver receives a combination of three different signals which are direct, reflected and diffracted rays [1]. When the receiver moves away from the reflection boundary which is angle 135° the lobing will be less complicated and the oscillation of the amplitude of the received signal reduces to a lower oscillation this is because the receiver receives a combination of two rays which are direct and diffracted rays. However, when the receiver moves away from the shadow boundary which is angle 225° it will receive only diffracted ray and this is result in preventing fading. In addition, As far as the receiver moves away the signal amplitude will be lower because it goes to those areas which are more shadowed such as in angle 240° the amplitude is less than -20 dB.

It is also interesting to investigate diffraction loss caused by a finitely conducting corner of a building. To do this, the polarization of the method is changed to parallel polarization. Figure (10) shows diffraction loss over proper 90° corners of building in GSM system when:
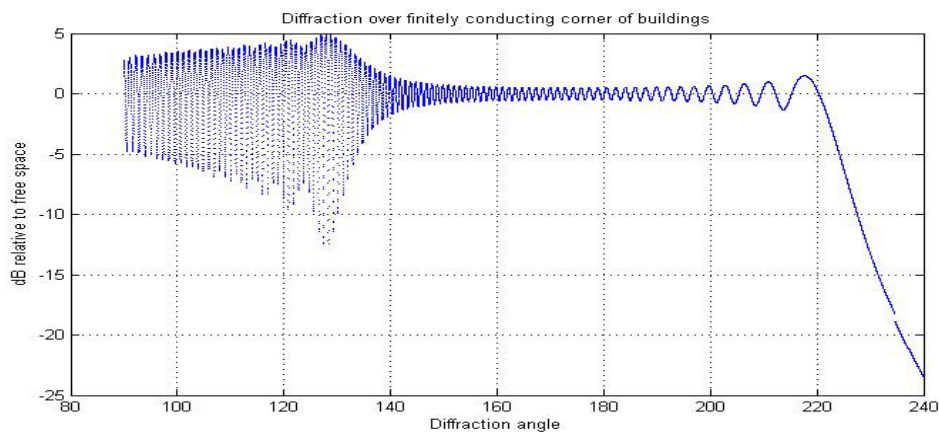s1 = 15 meter,
s2 = 15 meter

Figure 10. Diffraction over a finitely conducting corner of a building

Similarly, the above result is the same as the one in Figure (9) because in both cases it is assumed that the wedge and the corner are perfectly conducting. This makes the both equations (9) and (10) to be equal to -1 and the results will be the same.

However, it is also interesting to investigate different type of materials of the wedges or the corners. Figure (11) shows result of diffraction over a wedge which made of wood. It is assumed that the dielectric constant of wood is equal to 10 and the highest situation of conductivity is $3*10^{-5}\ S/m$.
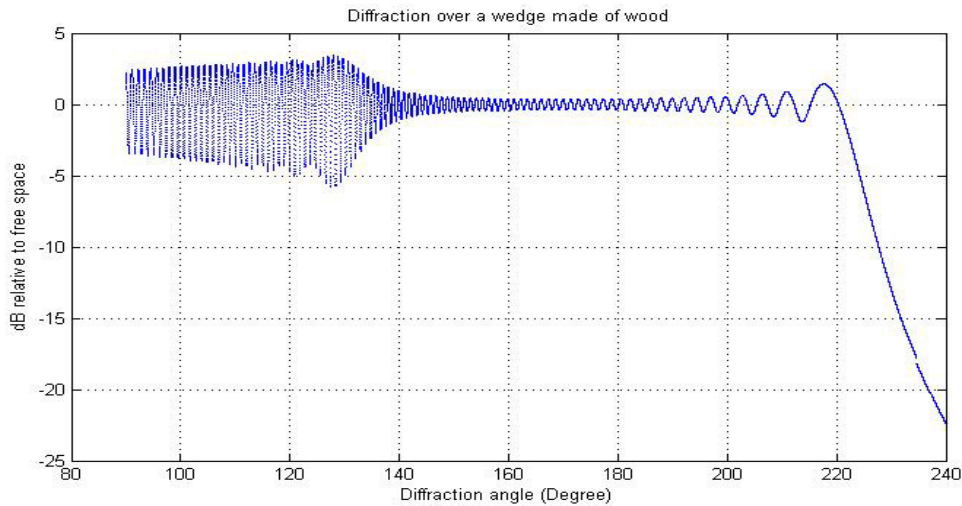

Figure 11. Diffraction over a wedge made of wood

As can be seen from the above figure, the fading and lobing of the received signal is nearly the same as a perfectly conducting wedge. However, the oscillation of the amplitude tends to decrease. For example, at the angle of 90° the minimum amplitude is nearly -3 dB while for a finitely conducting wedge is nearly -5 dB. In this case, at the angle of nearly 130° the lowest amplitude is nearly -5 dB. However, for a perfectly conducting wedge is nearly -12 dB. It can be said that the lower conductivity of the obstruction materials leads to have lower amplitude oscillation of the received signal at the receiver.

In order to investigate more material effects on the diffraction loss, different types of materials can be used. For example, some wedges are made of ceramics and the dielectric constant of ceramic is assumed to be nearly 6 and the conductivity varies according to the type of the ceramic made up the wedge [7]. In this case it is assumed to $10^{-7}\ S/m$.

Figure (12) shows diffraction over a ceramic wedge. Where:
The internal angle of the wedge = 90 degree.
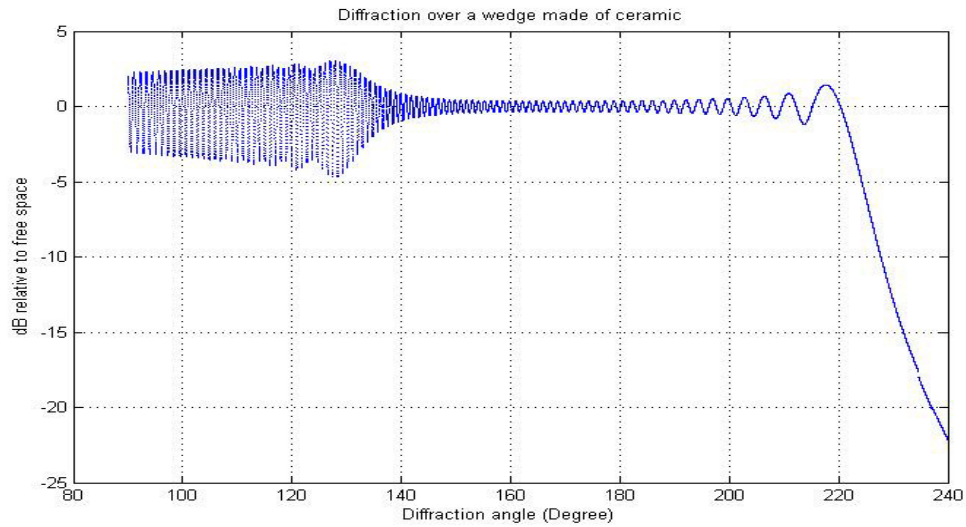s1 = 15 meter.
s2 = 15 meter.

Figure 12. Diffraction over a wedge made of ceramic

As described before, lower conductivity tends to lower amplitude oscillation of the signal at the receiver. In comparison, for above figure which the wedge made of ceramic the amplitude oscillation is lower than the one in Figure (11) which was the output of diffraction by a wooden wedge because the conductivity of ceramic is lower than the conductivity of wood. This fluctuation of amplitude can be noted in angle of 130° while in the wooden wedge the amplitude is lower than -5 dB. However for the ceramic wedge is greater than -5 dB.

Furthermore, diffraction by the corners of buildings also occurs, the material makes up the buildings is often brick. This brick originally may be made of ceramics. Figure (13) shows diffraction loss caused by a ceramic corner. It is known that the angle of the corners is mostly 90°.
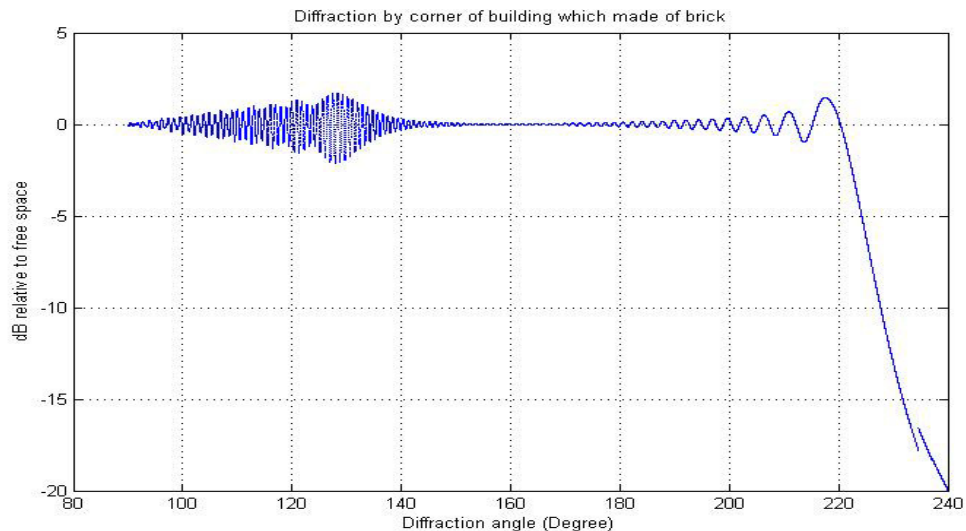s1 = 15 meter.
s2 = 15 meter.

Figure 13. Diffraction by a corner which is made of ceramic.

As can be seen from the above figure, the pick amplitude is much lower than the perfectly conducting corner in figure (10) because the conductivity here is low and lower conductivity results in lower amplitude. As compared to the diffraction by a wedge which made of ceramic in figure (12), here the amplitude of the received signal at 90° and 100° is nearly 0 dB. However, for perpendicular incident is between 2 and -2 dB. In addition, the amplitude oscillation between angles 145° and 170° is very low and fading tends to be unavailable.

Some values of the relative dB to the free space have been exported from the Matlab results to compare the amplitude oscillation for both perpendicular and parallel incident from diffraction angel of 90° to 220° for a wedge shaped obstacle made of ceramic. These values can be seen from Table (1).

Table 1. Received signal strength for a wedge made of Ceramic in both parallel and perpendicular polarization.

Angle (Degree)	Perpendicular (dB)	Parallel (dB)
90	2.026	- 0.0222
95	- 2.6348	0.1145
100	2.3506	- 0.4842
105	- 1.7146	0.3367
110	- 3.6803	0.8564
115	- 3.5502	0.8363
120	- 2.4803	1.0379
125	2.1043	- 0.7784
130	- 0.5952	0.8552
140	0.6533	- 0.1759
145	- 0.0778	0.0408
150	0.2083	- 0.035
155	0.1824	- 0.0139
160	0.1505	0.0023
165	- 0.0151	- 0.0022
170	0.3368	0.0618
180	- 0.1663	- 0.0565
185	- 0.4032	- 0.1623
190	0.4074	0.1981
195	0.0383	0.0183
200	0.4306	0.2697
205	- 0.4228	- 0.2959
210	0.4614	0.3511
215	- 0.2646	- 0.2149
220	0.2985	0.3144

As can be seen from above table, the amplitude of the received signal varies for each diffraction angle. It can be observed that from the above data the maximum amplitude is 2.356 dB and minimum is - 3.6803 dB for perpendicular polarization at angles 100° and 115° respectively. However this oscillation decreases to between 1.0379 dB and - 0.7784 dB for parallel polarization at angles 120° and 125° respectively. Moreover, the resolution of the angles is 5 degree if we take a smaller resolution we may obtain a greater oscillation of the amplitude at the other angles.

It can be said that the buildings have windows and sometimes these windows locate at the corner of the buildings. Clearly, these corner-shaped windows cause diffraction loss. However, the

conductivity and dielectric constant of the window material are taken into account. Mostly, windows are made of glasses and the conductivity of glass is assumed to be $10^{-11} \ S/m$ and the dielectric constant is nearly 4.6. Figure (14) shows diffraction loss caused by windows of buildings.
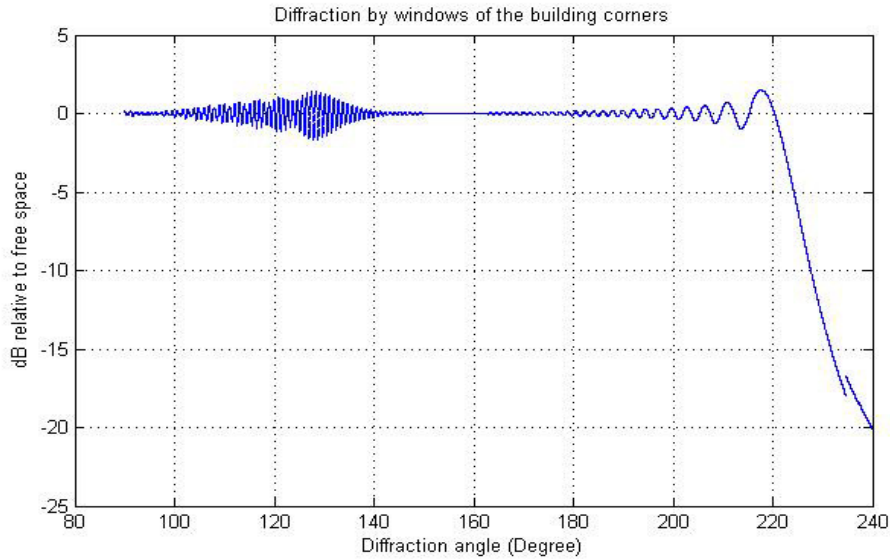

Figure 14. Diffraction by a corner which is made of Glass.

As can be seen from the above figure, due to the low conductivity of the material which makes the corner up the amplitude oscillation is very low at a rate in some positions of the receiver the received signal amplitude is 0 dB such as from 150° to nearly 163°. However, at those places where only the diffracted angle is available the received signal is the same as finitely conducting corners such as above 225° which means below the shadow boundary.

According to (Barclay, 2003) and (ITU-R Recommendation P.526-12) the result of knife edge diffraction can be obtained using wedge diffraction methods. To do this, the reflection coefficient should be assigned to 0 as well as the value of n should be equal to 2 in order to make the internal angle of the wedge to 0o. The result in this case should be the same as the one given in Figure (4). Figure (15) shows the result of knife edge diffraction using wedge diffraction implementation.
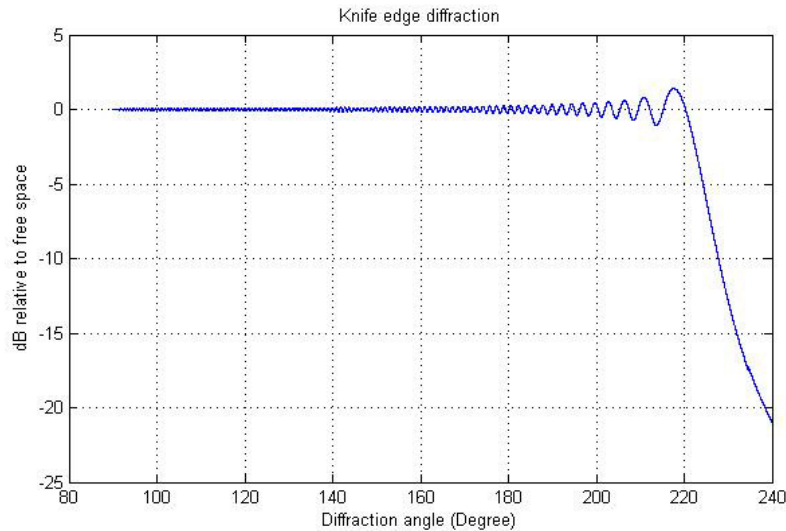
Figure 15. Knife edge diffraction loss.

In comparison, the results are the same. It can be said that, in the knife edge model implementation, the amplitude of the received signal for ν smaller than -0.7 is assigned to 0 [3]. This is an approximate value. However, in the knife edge model the loss is plotted versus ν parameter while in wedge diffraction it is versus the diffraction angle. It is clear that the ν parameter depends on the height of the obstacle and the Diffraction angle indicates the place of the receiver. Thus, the height of the obstacle can be found through the diffraction angle then ν parameter can be found using equation (1).

4. CONCLUSION

In conclusion, this paper has investigated loss caused by diffraction over the roofs and corners of the buildings which are wedge shaped. The method was to implement wedge diffraction based on UTD with two dimensions propagations which means the sender, receiver and the edge are in a straight line given in the (ITU-R Recommendation P.512-12). The importance of this paper is that the method takes the reflected and direct signals into account with respect of the diffracted ray. In addition, this method considers the electrical properties of the materials which made up the wedges such as conductivity and dielectric constant as well as it takes the polarization into account. Moreover, this model is pretty flexible in terms of widely using such as obtaining knife edge result. Several results were achieved for both parallel and perpendicular incident as well as for different materials. In addition, the results show that higher conductivity of the materials tends to have higher amplitude oscillation at the receiving point. As well as, diffraction loss caused by corners of buildings is more than that loss caused by the wedges for particular material. Unlike knife edge diffraction, this method considers the reflection from the edges. It can be suggested that in the future this model can be improved to investigate diffraction loss in three dimensions or diffraction by more than one wedge between the transmitter and the receiver as well as to estimate the other shapes of the obstacles such as round or random edges.

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